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PROPERTIES OF MULTILAYER FILTERS

Final Report

Covering the Period

March 1, 1967 to February 28, 1973

Research Grant No. NGL 33 019 003

with

National Aeronautics and

Space Administration

Washington 25, D.C.

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I Abstract

New methods were investigated of using optical interference coatings to produce bandpass filters for the spectral region 110 nm to 200 nm. The types of filter are: (1) Triple cavity metal dielectric filters (2) All dielectric reflection filters (3) All dielectric Fabry Perot type filters. The latter two types of filters use thorium fluoride and either cryolite films or magnesium fluoride films in the stacks. The optical properties of the thorium fluoride were also measured.

II Introduction

This report surveys the methods of producing optical interference coatings for the ultraviolet spectral region from 110 nm to 300 nm. The limit of 110 nm is imposed by the absorption of both the filming materials and the lithium fluoroide substrates. The motivation for studying this part of the spectrum is that filters are needed for optical instruments that are installed in both satellites and in rockets. Only in rare instances is it possible to purchase such coatings from commercial vendors. Also, only a few such coatings are produced by commercial firms and consequently there is little motivation for these firms to pursue a research program on the development of such coatings. This is particularly true of the vacuum uv region, where a costly vacuum uv monochromator is required to measure the radiant transmittance of the filters.

The program had two objectives: (1) The investigation of the properties of the optical properties of thin film coating materials for this spectral region. (2) The design of coatings, using the measured optical constants, as mentioned in the previous sentence. (3) The production of such coatings.

III Bandpass filters for a u.v. intensifier

Some bandpass filters were fabricated for Dr. Kenneth Hallam of Goddard Space Flight Center and were to be used in conjunction with an image intensifier. The filters were to have transmission peaks at 1200 \AA , 1550 \AA , and 1900 \AA . The target for the full width of the passband at $0.5 T_{\max}$ is 200 \AA and the transmission at 3000 \AA should be 0.001.

We briefly discuss some of the techniques used to produce these filters.

The primary problem was that of monitoring the thickness of the dielectric spacer layer in the center of the bandpass filter. For the bandpass filter at 1900 \AA , we used the design

air M_1 D M_2 D M_1 quartz .

The quarterwave optical thickness for D is 2400 \AA when the bandpass wavelength is at 1900 \AA . This means that it was not possible to monitor this optical thickness by measuring a quarterwave at the monitoring wavelength of 2536 \AA . We monitored the optical thickness of the dielectric layer by depositing it on a gold substrate. This has the advantage that the reflectance first falls to a minimum and then increases. On our equipment, the minimum was at a relative value of 62 units and the

stopping point was at 78 units (relative to 100 units, for the uncoated gold). This makes it possible to compensate for any drift in the mercury lamp intensity or in the electronics. For example, due to drift in the electronics, we found that the minimum reading was at 60, rather than the expected 62. We would compensate for this downward drift by halting the evaporation a little earlier.

Three identical filters were required. We therefore fabricated a substrate rotator that held three 1.75 inch diameter substrates. The motor that drove the rotator was "potted" in a vacuum tight, water cooled stainless steel container and the rotary motion was fed out through a magnetic lead thru. The filter holder had a cover that protected the substrates from dust until after they were in the chamber and pumped to low pressure. The cover was removed by burning through the thin copper wires that held the cover in place, just prior to evaporation.

We were extremely careful about dust contamination on the substrates. They were cleaned in chromic acid, rinsed in distilled water and dried with dry nitrogen in a clean box.

The spectral transmittance of a typical filter is shown in Fig. 1. It has a peak transmittance of nearly 6% and has an attenuation of five density units at 3000 \AA . The filters were reasonably close to the specifications set out by Dr. Hallam. They were delivered

to Goddard Center in July, 1970. Another report¹ describes the filters for the 1550 Å and 1200 Å regions.

IV Reflection filters

Reflection filters offer an attractive means of providing a substantial transmittance at short wavelengths and a large attenuation at longer wavelengths. Figure 2 shows the arrangement of a reflection filter in the two bounce and four bounce configurations.

Several reflection filters were fabricated for the spectral region below 2000 Å. The filters consist of four identical reflectors, as shown in Fig. 2. Thorium fluoride was used as the high index material and cryolite as the low index material in the reflectors.

The reflectors for the filters were of identical design

$$V (HL)^{15} H S$$

where V is the incident medium and S is the substrate. H represents a quarterwave of the high index material and L a quarterwave of the low index material at the design wavelength.

The four reflectors for each filter were produced simultaneously by electron beam evaporation at a maximum pressure of approximately 8×10^{-6} torr. The optical

thickness was monitored in transmission on quartz monitor plates at a wavelength of 2536 \AA . To obtain the thickness difference between the monitor plate and the substrates, a wedge shaped mask was placed in front of the substrate rotator. The substrate rotator was capable of holding four elements at once, thus insuring that the elements in the completed filters were very nearly identical.

The completed high reflectors were removed from the evaporator and were loaded into the body of the reflection filter. The measured transmittance of a typical filter is depicted in Fig. 3. The measurements were made on the McPherson vacuum monochromator below 2000 \AA . For wavelengths above 2000 \AA , either the Cary Model 14, or the McPherson with a quartz blocking filter was used. The reflectors were deposited on one inch diameter magnesium fluoride substrates manufactured by the Harshaw Chemical Company.

The following table summarizes the properties of the filter:

T_{\max}	λ_{\max}	$\Delta\lambda$	R_{av}
0.52	1800 \AA	170 \AA	0.85

R_{av} is $4\sqrt{T_{\max}}$ and represents the average radiant reflectance of one reflector.

V. Multilayer dielectric interference filters

Most of the filters produced for the vacuum ultraviolet spectral region contain two or more aluminum films. We produced several Fabry Perot type filters and also measured the optical constants of the optical coating materials that were used in the filters.

Several all dielectric Fabry Perot interference filters were fabricated in the spectral region below 2000 Å. Thorium fluoride was used as the high index material and cryolite (Na_3AlF_6) was the low index material. The substrates were one inch magnesium fluoride from the Harshaw Chemical Company.

The filters were of the design

$$V \text{ (HL)}^8 \text{ HH (LH)}^8 \text{ S .}$$

V and S represent the incident medium and substrate respectively, while H signifies a layer of ThF_4 of one quarterwave optical thickness at the design wavelength and L is a layer of Na_3AlF_6 of the same optical thickness.

The optical thicknesses of the layers were monitored in transmission at a wavelength of 2536 Å through a quartz monitor plate. To obtain the difference in thickness between the monitor plate and the substrate, a wedge shaped aluminum mask was placed between the rotator and

the evaporation source. The wedge was approximately one half inch in front of the plane of the substrate rotator, and the apex of the wedge was placed in line with the axis of the substrate rotator.

During the evaporation the substrate rotator was run continuously. Due to the presence of the wedge, the substrate was not exposed to the evaporation continuously, but only for some fraction of the total evaporation time.

The measured and computed transmittance of a typical filter is shown in Figs. 4 and 5. The computed curves take into account the absorption of the magnesium fluoride substrates. There is reasonable agreement between the measured and calculated curves.

The optical constants of the thorium fluoride were determined by depositing a thick film and measuring its spectral transmittance, as shown in Fig. 6. The position of the maxima and minima in the transmittance curve furnish information on the film's refractive index and the attenuation gives information about the absorption part of the optical constant. The complex optical constant is $\hat{n} = n - j$ and is shown in Figs. 7 and 8. The thorium fluoride is manufactured by Balzers. These data are in agreement with those of Heitmann³.

VI Combinations of filters

A study was also made of the use of combinations of filters -- that is, a series of filters are "ganged" so that the flux transverses the entire chain. The objective is to decrease the transmittance in the offband spectral region. This material is not discussed here, since it has been published⁴.

VII References to the literature

1. Properties of Multilayer Filters, Interim Report covering the period March 1, 1970 to August 31, 1970; Research Grant No. NGL 33 019 003 with National Aeronautics and Space Administration, Washington 25, D.C. Principal Investigator: P. W. Baumeister.
2. A. Ennos, "Stresses Developed in Optical Coatings" Appl. Opt. 5, 51 (1966).
3. W. Heitmann, and E. Ritter, "Production and Properties of Vacuum Evaporated Thorium Fluoride", Appl. Opt. 7, 307 (1968).
4. P. Baumeister, R. Hahn, and D. Harrison, "The Radiant Transmittance of Tandem Arrays of Filters" Optica Acta 19, 853 (1972).

VIII The following personnel contributed to
the research in this report:

Philip Baumeister

James Buran

Charles Carniglia

Jay Eastman

Robert Hahn

Douglas Harrison

IX Publications

The following publication was produced under the
auspices of this grant:

"The Radiant Transmittance of Tandem Arrays
of Filters" by P. Baumeister, R. Hahn, and
D. Harrison. Optica Acta 19, 853 (1972).

X Captions to the Figures

1. The measured spectral transmittance of a bandpass filter of the design

$D' \quad M_1 \quad D \quad M_2 \quad D \quad M_1 \quad \text{substrate}$

where the substrate is ultraviolet quality fused quartz, 1.75 inches in diameter. The layers \underline{D} and \underline{D}' represent films of magnesium fluoride and are spacer layers and a protective overcoat, respectively. The \underline{M} layers are aluminum.

2. Showing the arrangement of the reflectors in a reflection filter in the two bounce and four bounce configurations.
3. The measured transmittance of a four element reflection filter with peak transmission at 1800 \AA ,
The reflecting elements are the design

$V \quad (H \quad L)^{15} \quad H \quad S$

The substrates are one inch blanks of magnesium fluoride.

- H Signifies a layer of a quarterwave optical thickness of ThF_4 at the design wavelength.
- L Signifies a layer of a quarterwave optical thickness of Na_3AlF_6 at the design wavelength.

4. The measured transmittance of a filter of the design

$$V (H L)^8 HH (L H)^8 S$$

The design wavelength is $1775 \overset{O}{\text{\AA}}$ and the substrate is a one inch diameter blank of magnesium fluoride.

5. The computed transmittance of the filter of Fig. 4.
6. The measured transmittance of an evaporated layer (10 quarterwaves optical thickness at $2680 \overset{O}{\text{\AA}}$) of thorium fluoride, as manufactured by Balzers. The points represent computed values using the experimentally determined values of the optical constants for this material.
7. The refractive index n of the ThF_4 film cited above.
8. The absorption constant k of the ThF_4 film cited above.

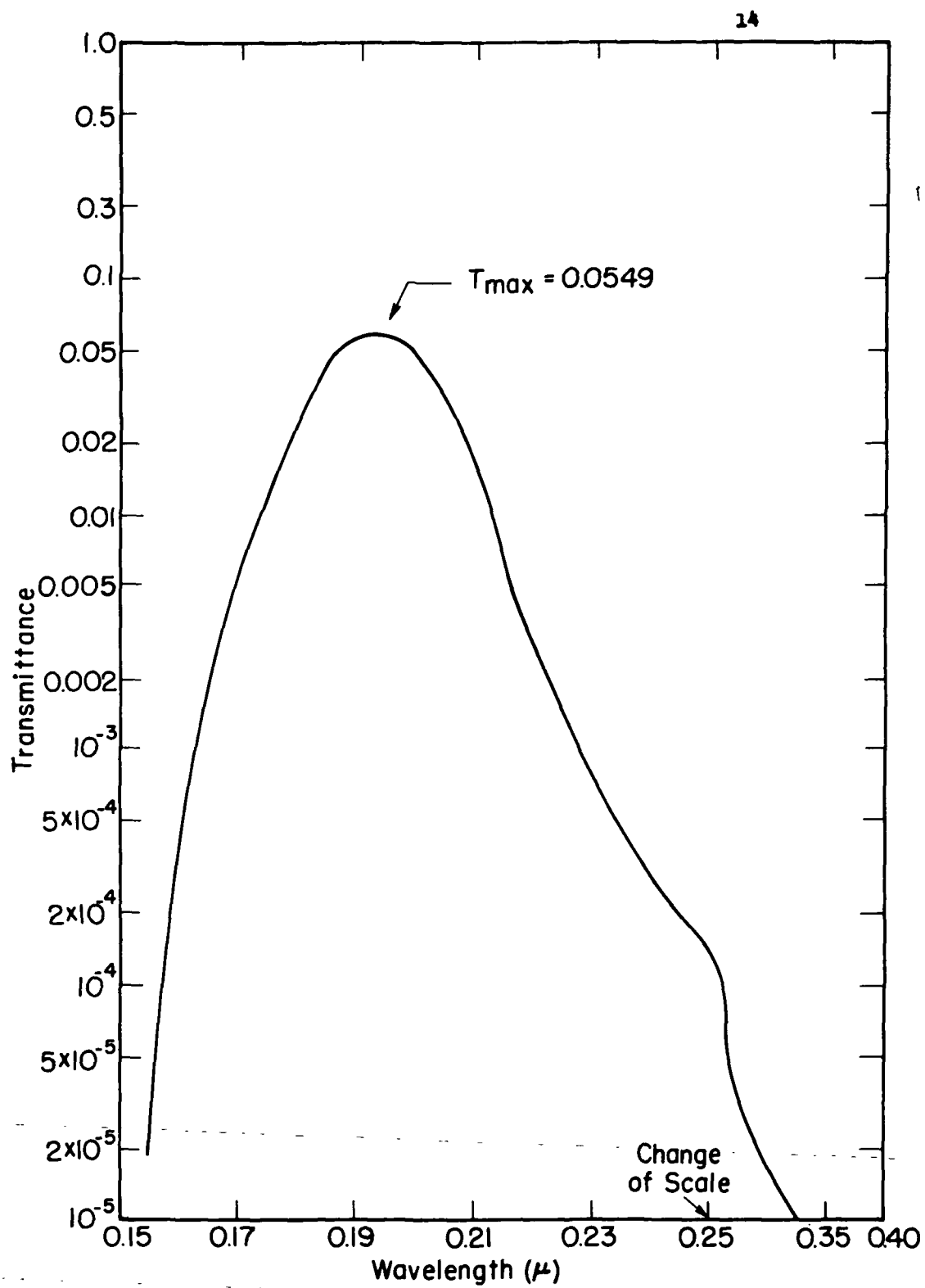


Fig. 1

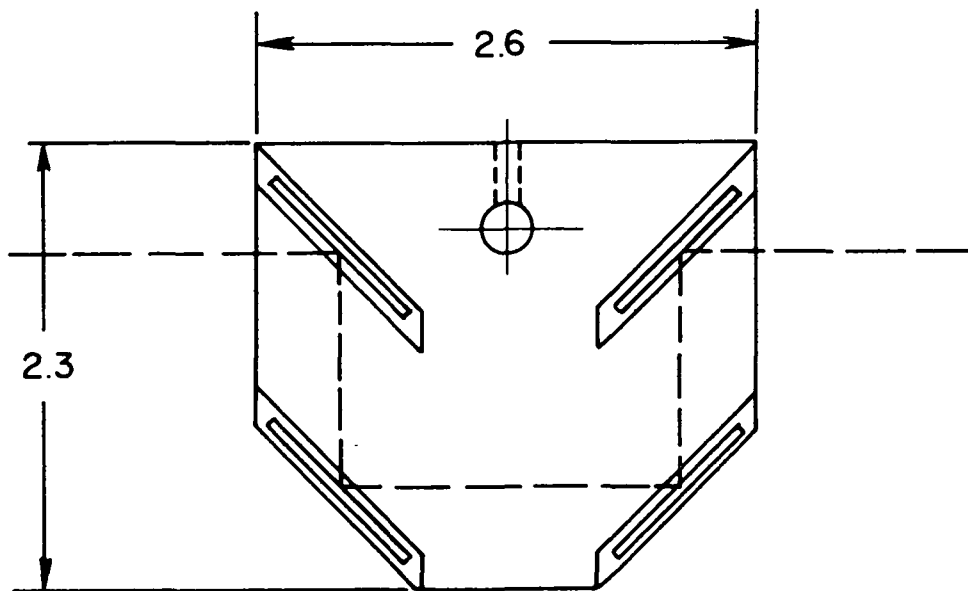
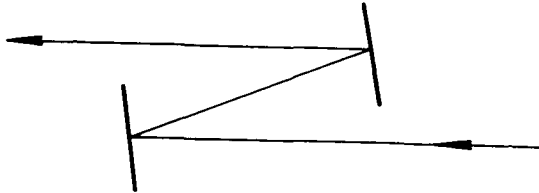


Fig 2

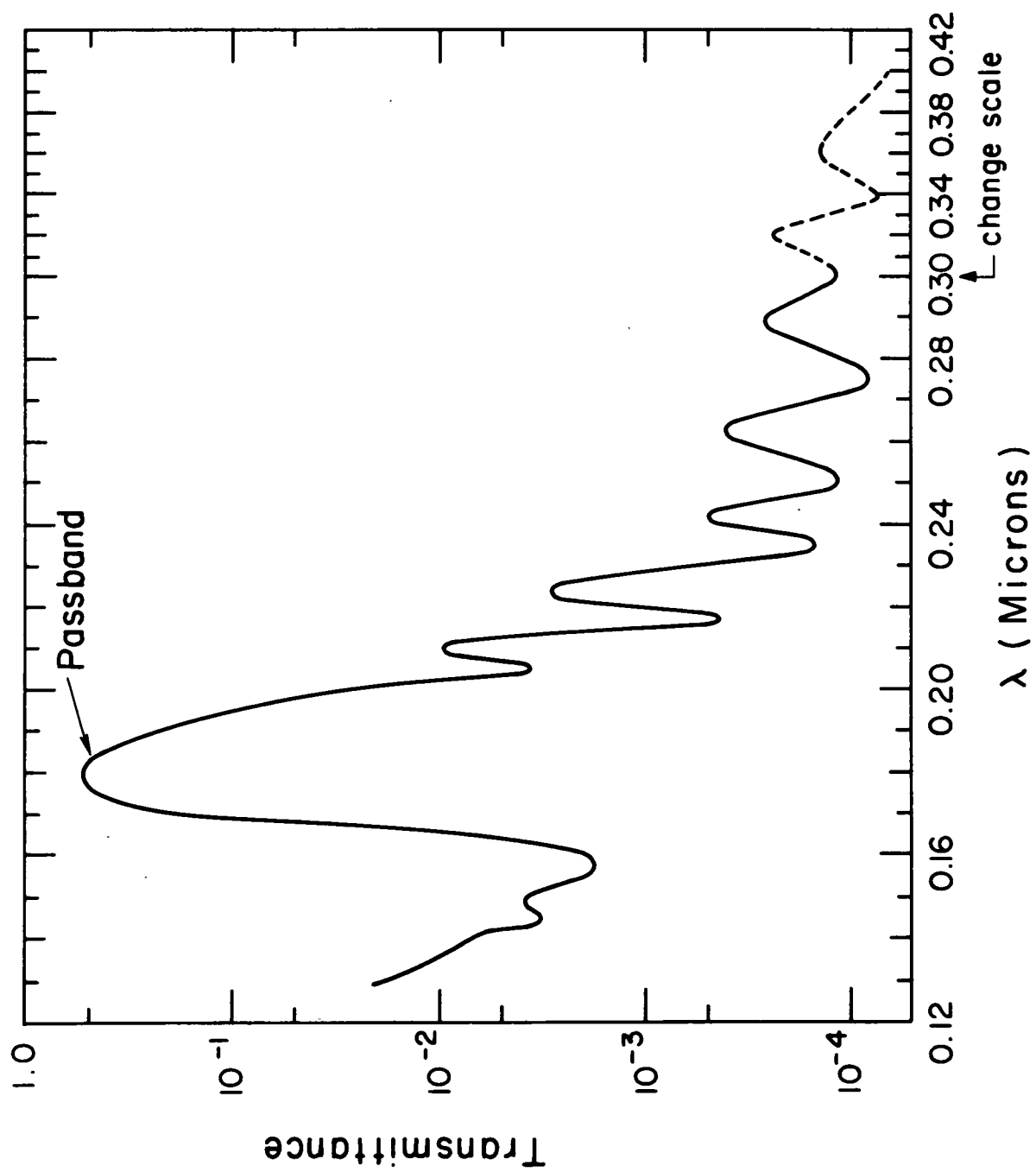


Fig 3

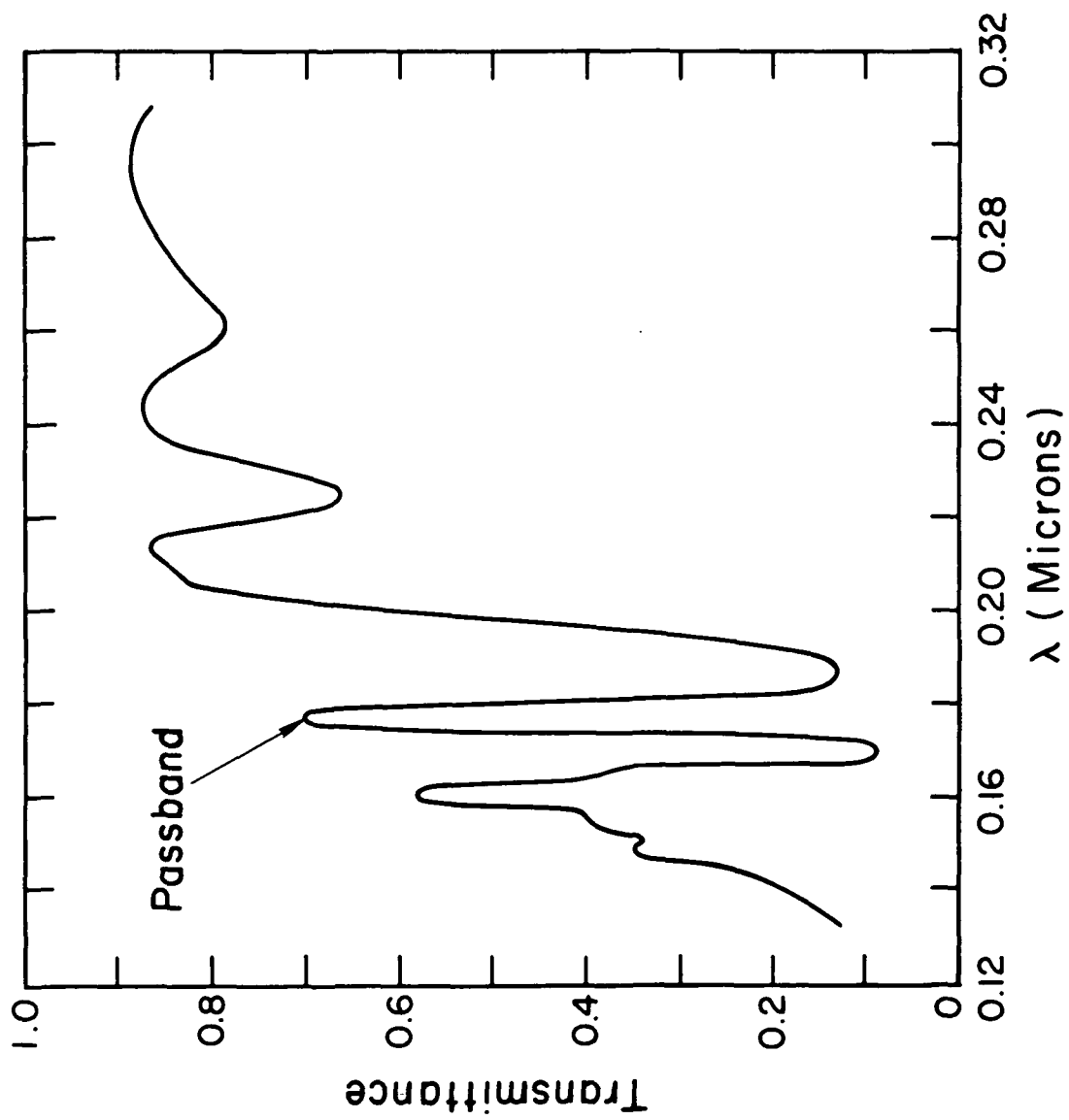


Fig 4

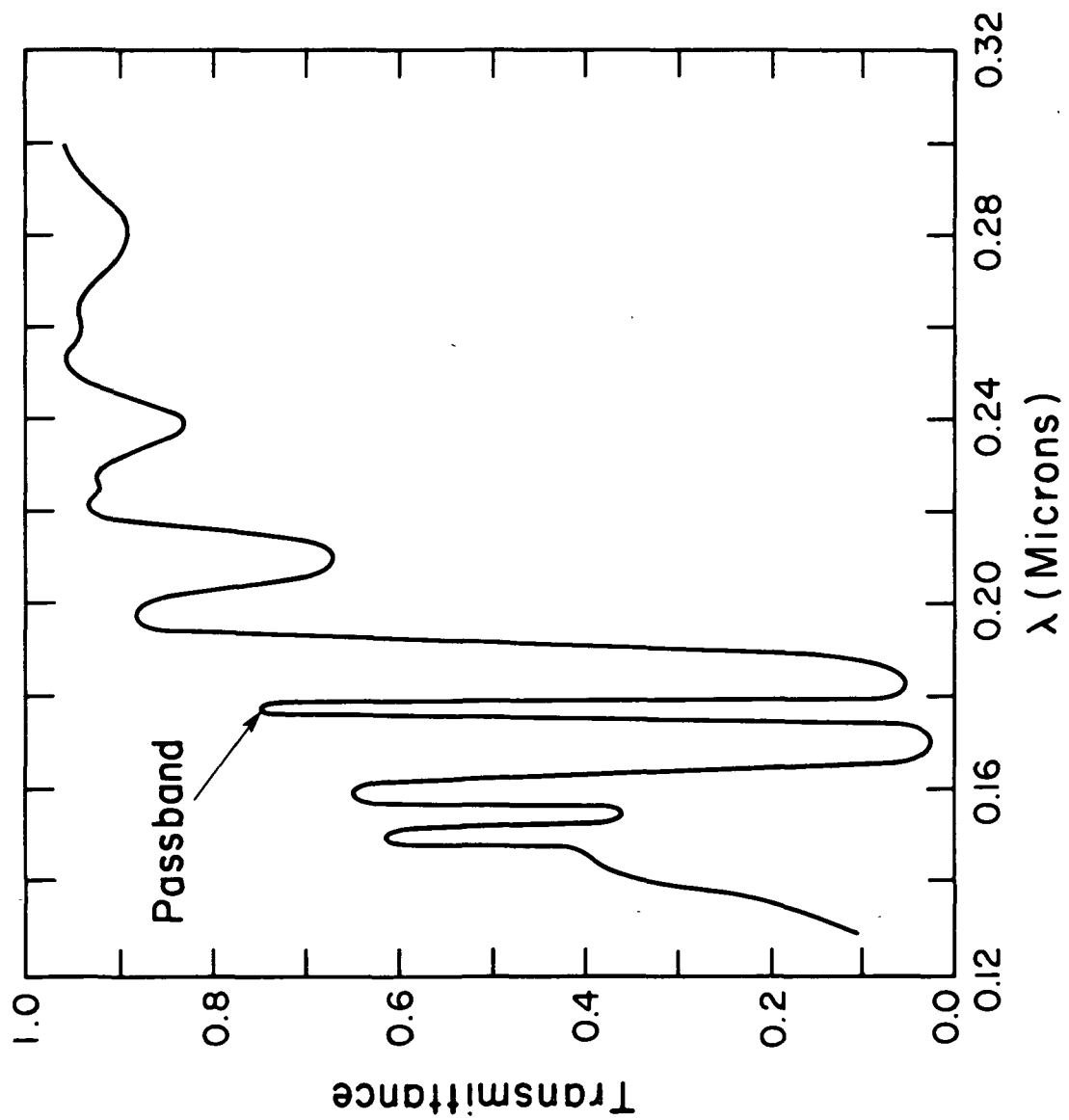


Fig 5

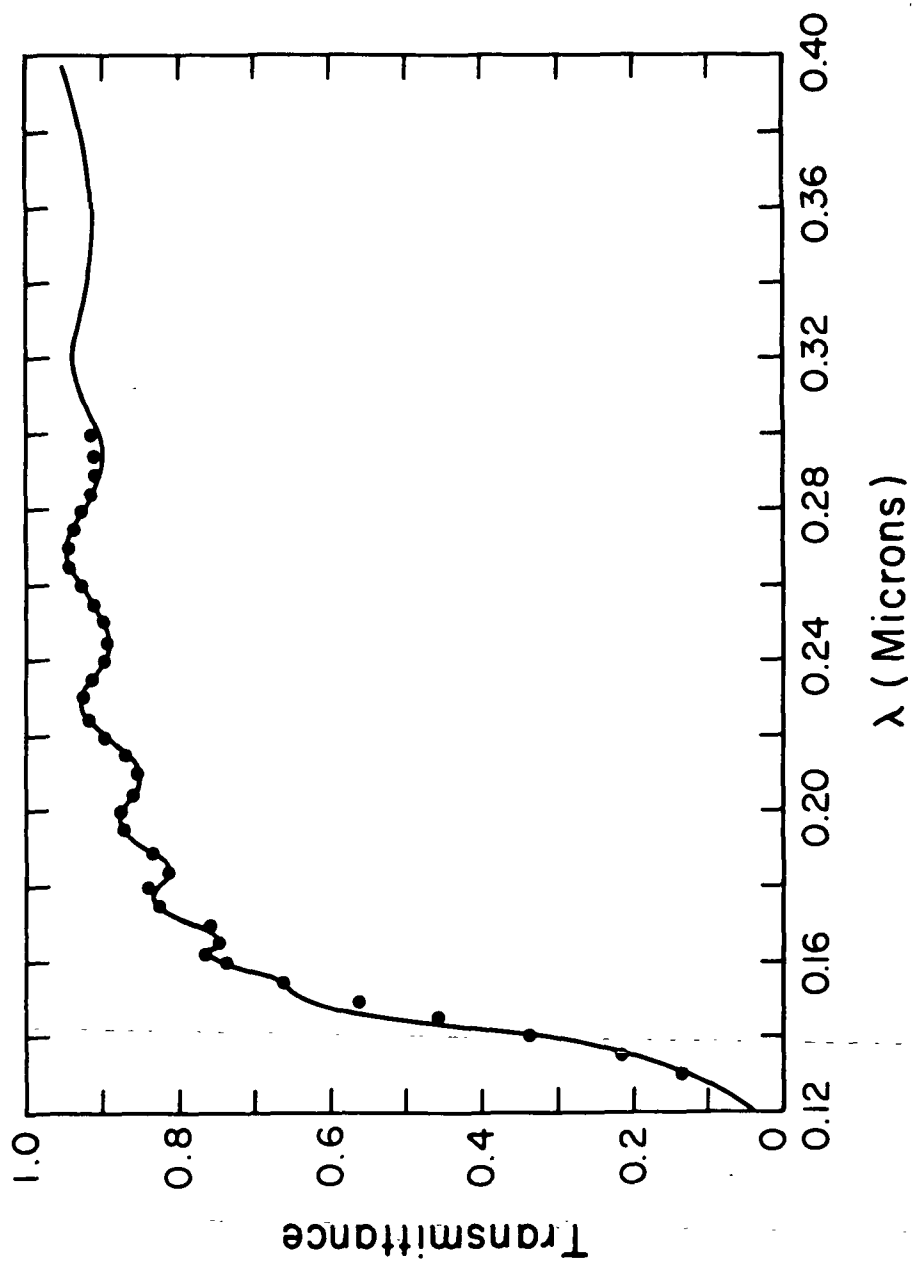


Fig 6

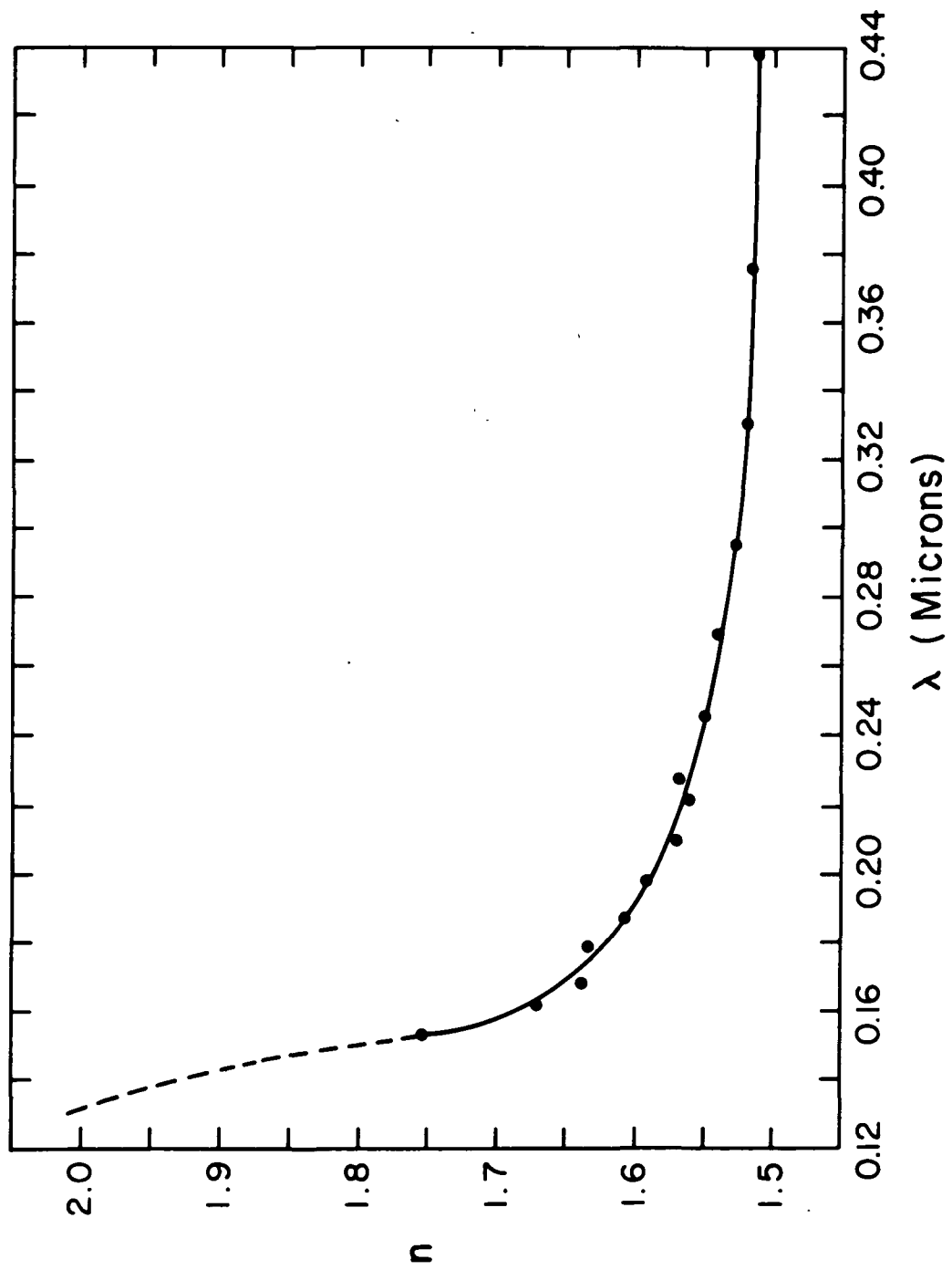


Fig 7

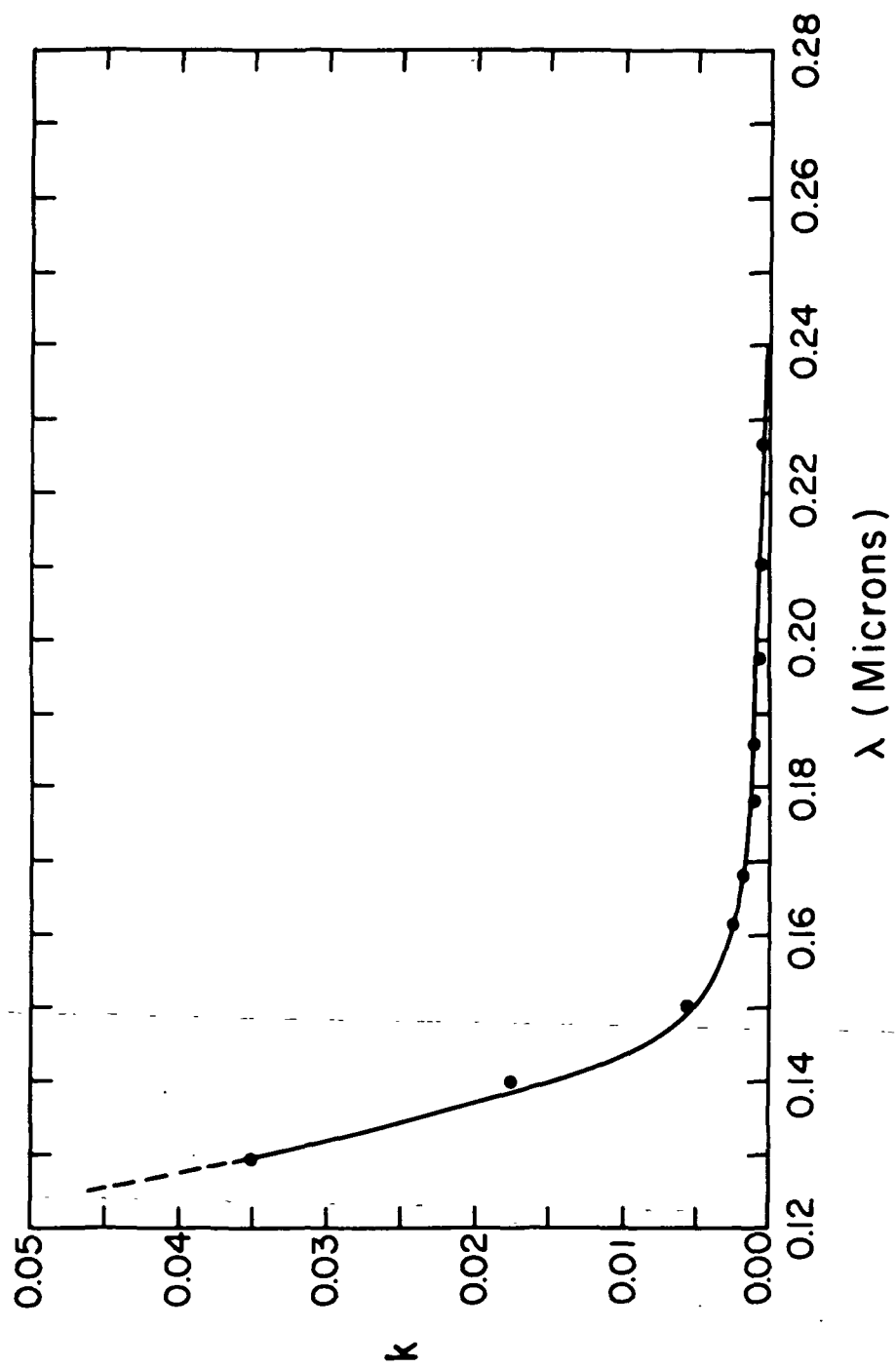


Fig 8